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U.S. Department of Energy
Office of Civilian Radioactive Waste Management

Structural Deformation and Seismicity

Presented to:
NRC/DOE Technical Exchange on Yucca Mountain Pre-Licensing Issues

Presented by:
J. Timothy Sullivan
Yucca Mountain Site Characterization Office
U. S. Department of Energy

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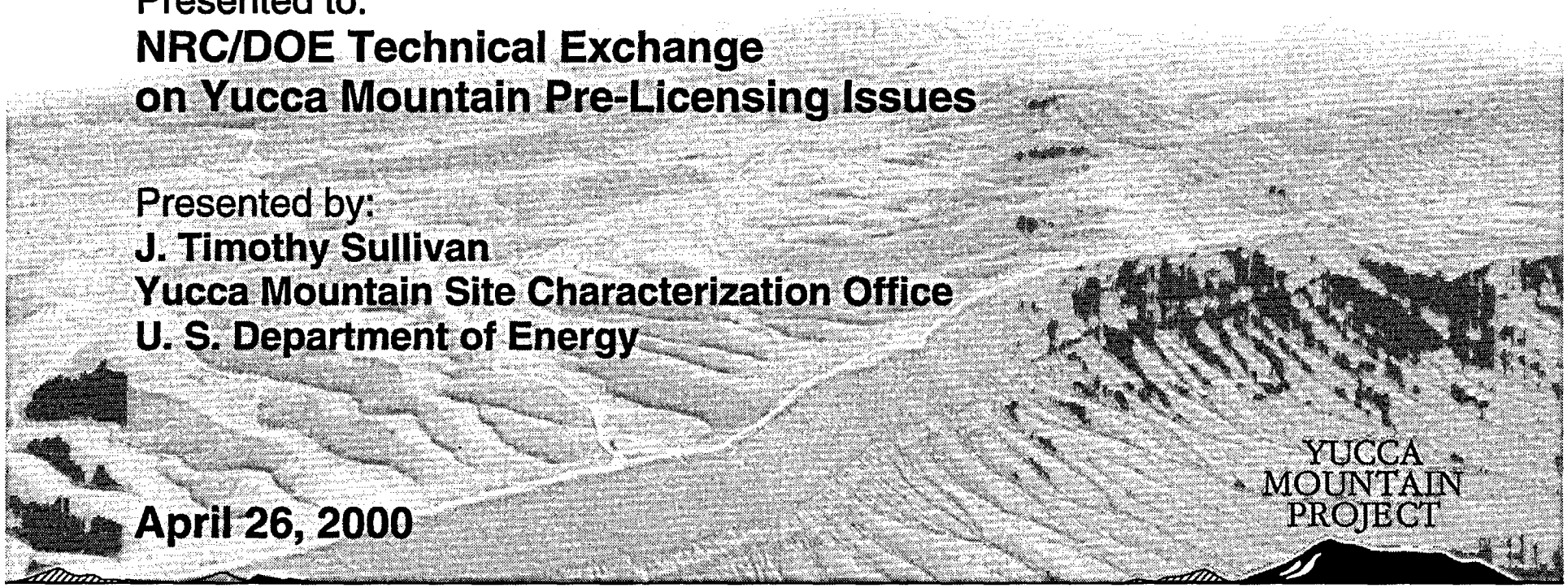

Key Technical Issue - Structural Deformation and Seismicity

- **The scope of this Key Technical Issue (KTI) includes:**
  - **Elements that may affect the evaluation of faulting and earthquake effects on long-term performance and postclosure waste containment and isolation**
  - **Elements that affect development of the preclosure seismic design inputs**

Outline of Presentation on Earthquake-Related Analysis

- Overall subissue status
- Key activities related to structural deformation and seismicity
- Subissue discussion
- Summary
- Backup

Current Status

(Issue Resolution Status Report Revision 2)

- **Subissue 1 - Faulting**
  - All technical acceptance criteria are resolved
- **Subissue 2 - Seismicity**
  - Two technical acceptance criteria are resolved
  - Four technical acceptance criteria are open
- **Subissue 3 - Fracturing and Structural Framework of the Geologic Setting**
  - All technical acceptance criteria are open
- **Subissue 4 - Tectonic Framework of the Geologic Setting**
  - All technical acceptance criteria are resolved

Key Activities

- **Fiscal Year (FY) 1998**
  - **Completed Probabilistic Seismic Hazard Analysis (PSHA) culminating more than a decade of seismic hazard investigations in the Yucca Mountain area**
  - **Used PSHA results (hazard curves) as input to seismic effects scenarios in Total System Performance Assessment - Viability Assessment (TSPA-VA)**
  - **Developed methodology for determining seismic response spectra and time histories for design**

Key Activities
(Continued)

- **FY 1999**
  - Developed preliminary ground motion site response information based on limited site data
  - Developed preliminary seismic design inputs for Site Recommendation (SR)
  - Received NRC request for PSHA data input files

Key Activities
(Continued)

- **FY 2000**
  - Updated design input analyses for use in SR design analysis, including motions for a soil site with assumed engineered fill as the top layer
  - Completing dynamic analysis of Waste Handling Building to identify seismic vulnerabilities
  - Established the basis for analysis of postclosure seismic effects
  - Provided NRC PSHA data input files
  - Initiated Waste Handling Building geotechnical investigations for the License Application (LA)
  - Plan to provide seismic effects analyses results and Analysis and Model Reports (AMRs), Disruptive Events Process Model Report (PMR), and TSPA-SR

Key Activities
(Continued)

- **FY 2001**
  - **Plan to complete geotechnical investigations at Waste Handling Building**
  - **Plan to develop final design inputs**
  - **Plan to provide Seismic Topical Report-3 to NRC (11/01)**

KTI Subissues and Associated Factors of the Safety Case

	KTI Subissues	Associated Factors of the Safety Case	Importance to Repository Performance
1	Faulting	To be determined (TBD)	Disruptive events will be evaluated as part of Repository Safety Strategy process.
2	Seismicity	TBD	
3	Fracturing and Structural Framework of the Geologic Setting	TBD	
4	Tectonic Framework of the Geologic Setting	TBD	

Subissue 1, Faulting

- All acceptance criteria, except those related to quality assurance (QA), are resolved
- All features, events, and processes (FEPs) associated with faulting effects on unsaturated zone flow (UZ), saturated zone flow (SZ), waste package, and engineered barrier system (EBS) have been excluded from the TSPA
- Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)
- Preclosure design criteria, including fault avoidance, ensure that fault displacement is not a significant factor for preclosure

Subissue 2, Seismicity

- Two Criteria resolved; 4 Criteria open
- All FEPs associated with seismic effects on UZ flow, SZ flow, waste package, and EBS have been excluded from TSPA
- Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)
- Preliminary analyses indicate that vibratory ground motion is an issue for preclosure surface design, but analyses will have to demonstrate design requirements have been met

Subissue 2, Seismicity
(Continued)

- Work is in progress to collect information needed to finalize seismic design motions for specific facilities, such as the Waste Handling Building
- DOE anticipates that NRC review of Seismic Topical Report-3 will lead to resolving open items

Subissue 3, Fracturing and Structural Framework of the Geologic Setting

- All acceptance criteria are open
- Features Events and Processes screening results are reported in the AMR *Disruptive Events Features, Events, and Processes (*ANL-WIS-MD-000005)
- NRC has concerns over completeness of fracture information
  - Origin of fractures
  - Sampling bias

Subissue 3: Fracturing and Structural Framework of the Geologic Setting

(Continued)

- DOE believes an adequate basis exists for representing fracture effects in TSPA
- These acceptance criteria are addressed by DOE in UZ Flow and Transport and SZ Flow and Transport PMRs (UZ Flow and Transport PMR, Sections 3.3, 3.4, 3.6.3.2, 3.7, 3.9; SZ Flow and Transport PMR, Sections 3.2.2.4, 3.2.2.5, 3.2.3.4, 3.6.3.3.1)

Subissue 4 - Tectonic Framework of the Geologic Setting

- All acceptance criteria, except those related to QA, are resolved
- All FEPs associated with non-igneous, tectonic effects on UZ flow, SZ flow, waste package, and EBS have been excluded from TSPA
- Bases for exclusions will be provided in AMR, *Disruptive Events Features, Events, and Processes* (ANL-WIS-MD-000005)

Subissue 4 - Tectonic Framework of the Geologic Setting
(Continued)

- **DOE recognizes that NRC still has concerns related to "inconsistent" treatment of tectonic models in Probabilistic Volcanic Hazards Analysis and PSHA**
  - **This will be addressed in the Disruptive Events PMR and subsequent interactions**

Summary

- All technical criteria related to Subissue 1, Faulting, and Subissue 4, Tectonic Framework, are resolved
- For TSPA-SR (11/00), DOE will have completed a full seismic effects analysis for the nominal scenario
- For the Site Recommendation Consideration Report (11/00), DOE will have developed
  - Preliminary preclosure seismic design basis information based on limited site ground motion response data
  - Dynamic analysis of the Waste Handling Building using preliminary preclosure seismic design basis information
- Further interactions should lead to resolution of remaining issues with fracture information and tectonic models

Summary

- DOE's planned investigations and analyses will lead to completion of Seismic Topical Report-3 in 11/01
- NRC review of Seismic Topical Report-3 should lead to resolution of open criteria for the seismicity subissue related to preclosure seismic design methodology

Backup

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
Subissue 1: Faulting (Fault Displacement Hazard)		
1 – Sufficient geological and geophysical data are acquired to adequately support conceptual models of faulting, attendant assumptions, and boundary conditions and to define relevant parameters implemented in process level models and TSPA calculations of the direct disruption of WPs from faulting.	Resolved	Agree
2 – Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to develop process, TSPA, or both models of faulting are technically defendable and reasonably account for uncertainties and variabilities.	Resolved	Agree
3 – Alternative modeling approaches for faulting are investigated, consistent with available scientific understanding. Results and limitations are appropriately considered in the development of the probabilistic fault displacement hazard models and included in abstractions for process level and TSPA subsystem models.	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
4 - Results of PFDHA [Probabilistic Fault Displacement Hazard Analysis], TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observation, or both.	Resolved	Agree
5 - Incorporation of faulting models and parameters into TSPA models adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstraction process.	Resolved	Agree
6 - Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Resolved	Agree
Subissue: Seismicity (Vibratory Ground Motion Hazard)		
1- Sufficient geological and geophysical data are acquired to adequately define seismic	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
sources, relevant earthquake and GM parameters, recurrence relationships, GM attenuation functions, and boundary conditions, and to support attendant assumptions and conceptual models implemented in TSPA.		
2 - Parameter values, assumed ranges, probabilistic distributions, and bounding assumptions used to determine seismicity parameters are technically defensible and reasonably account for uncertainties and variabilities.	Open; pending detailed analyses. Seismic hazard is sensitive to uncertainties associated with recurrence rates and the attenuation model.	Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level, and the surface of the emplacement block.
3 - Alternative modeling approaches for seismicity model, such as recurrence relationships of GM attenuation relationships, are investigated. Results and limitations are considered in the development of the PSHA and included in the abstractions to TSPA subsystem models, consistent with available data and current scientific understanding.	Open; pending detailed analyses.	Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level , and the surface of the emplacement block.
4 - Results of PSHA, TSPA subsystem, or both models are verified by comparison to output from detailed process models, empirical observation, or both.	Open; pending acquisition of seismic data.	1. Complete ongoing location-specific work and evaluations and determine seismic design ground motions at the location of the Waste Handling Building, at the waste emplacement level, and the surface of the

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
		emplacement block. 2. Complete evaluations of the response of the repository system to ground motion hazard for input to postclosure TSPA.
5 - Incorporation of seismicity models and parameters into PSHA, TSPA, or both adequately includes important design features, physical phenomena, and coupling and relies on consistent and appropriate assumptions throughout the abstractions process.	Open	1.Complete evaluations of the response of the repository system to ground motion hazard for input to postclosure TSPA. 2. Complete analysis of response of the repository system to fault displacement hazard for input to the TSPA.
6 - Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Resolved	Agree
Subissue 3: Fracturing and Structural Framework of the Geologic Setting		
1 - Adequate field, borehole, and underground excavation data are acquired to sufficiently support conceptual models,	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
assumptions, and boundary conditions of numerical abstractions of fracture data and fracture models of ambient and perturbed conditions.		
2 - Parameter values, assumed ranges, probability distributions, and bounding assumptions used to determine fracture distributions and properties reasonably account for uncertainties and variabilities.	Criterion may not be met. Results of NRC evaluation to be reported in Rev 3 of SD&S IRSR.	Not addressed by DE PMR.
3 - Alternative modeling approaches for fracture distribution and properties of fractures consistent with available data and current geologic understanding are investigated and results and limitations are appropriately considered in process, TSPA, or both models of ambient and perturbed repository conditions.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.
4 - Results of fracture data analyses and fracture models are verified by comparison with output of sensitivity studies, detailed process level models, natural analogs, and empirical observations, as appropriate.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
5 - Results of abstractions of fracture data are consistent [with] physical and geological phenomena and coupled processes.	Criterion may not be met. NRC will systematically evaluate importance of fractures and fracturing on dose in other KTI integrated subissues (e.g. USFIC, ENFE, TEF [SD&S IRSR Rev 2, p4])	Not addressed by DE PMR.
6- Collection, documentation, and development of data and models was performed under acceptable QA procedures or has been qualified under appropriate QA procedures.	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 - Expert elicitations were conducted and documented using guidance in NUREG-1563 or other acceptable approaches.	Criterion does not apply. No expert elicitations were conducted to characterize fractures.	Agree.
Subissue 4: Tectonic Framework of the Geologic Setting		
1 - Sufficient geological information and geophysical data are available to adequately support conceptual models of tectonics, attendant assumptions, and boundary conditions and to define relevant parameters of tectonic models implemented in process, subsystem, or PA models and calculations.	Resolved	Agree
2 - Parameter values, assumed ranges, probabilistic distributions, and/or bounding assumptions used to develop viable tectonic	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
models are technically defendable and reasonably account for uncertainties and variabilities.		
3 - Alternative modeling approaches for tectonics are investigated, consistent with available data and current scientific understanding. Results and limitations of tectonic models are sufficiently considered in the development of process, subsystem and TSPA models.	Resolved	Agree
4 - Viable tectonic models are verified within the context of all geological and geophysical data [and] the tectonic framework of the geologic setting.	Resolved	Agree
5 - Incorporation of tectonic models into PSHA, Probabilistic Volcanic Hazards Assessment (PVHA) and TSPA adequately includes major structural features, physical phenomena, and coupling important to design and performance and relies on consistent and appropriate assumptions throughout the abstraction process.	Resolved	Agree

Key Technical Issue: Structural Deformation and Seismicity		
Acceptance Criterion	**SD&S IRSR Rev. 2 Status**	**DOE Comment**
6 – Quality Assurance	Open; TBD	Process Validation and Reengineering (PVAR) and other key initiatives provide procedural framework guiding development of DE PMR and the supporting AMRs and calculations.
7 – Expert Elicitation	Resolved	Agree

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.01.01.00	Tectonic activity—large scale	*Exclude*	Low Consequence
1.2.01.01.01	Folding, uplift or subsidence lowers facility with regard to current water table	*Exclude*	Low Consequence
1.2.01.01.02	Tectonic changes to local geothermal flux causes convective flow in SZ and elevates water table	*Exclude*	Low Probability
1.2.01.01.03	Tectonic folding alters dip of tuff beds, changing percolation flux	*Exclude*	Low Consequence
1.2.01.01.04	Uplift or subsidence changes drainage at the site, increasing infiltration	Exclude	Low Consequence
1.2.01.01.08	Uplift and subsidence	*Exclude*	Low Consequence
91.2.02.01.00	Fractures	*Include*: existing characteristics / *Exclude*: changes to characteristics.	Low Consequence
1.2.02.02.00	Faulting	*Include*: existing characteristics/ *Exclude*: changes in fault properties.	*Excluded* based on low consequence, and low probability
1.2.02.02.05	Faulting/Fracturing	*Include*	
1.2.02.02.08	Normal faulting occurs or exists at Yucca Mountain	*Include*	
1.2.02.02.09	Strike/slip faulting occurs or exists at Yucca Mountain	*Include*	

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.02.02.10	Detachment faulting occurs or exists at Yucca Mountain	*Exclude*	Low Consequence
1.2.02.02.11	Dip/slip faulting occurs at Yucca Mountain	*Include*	
1.2.02.02.12	New fault occurs at Yucca Mountain	*Exclude*	Low Consequence
1.2.04.02.03	Volcanic activity in the vicinity produces an impoundment	*Exclude*	Low Consequence
1.2.02.02.13	Old fault strand is reactivated at Yucca Mountain	*Exclude*	Low Consequence
1.2.02.02.14	New fault strand is activated at Yucca Mountain	*Exclude*	Low Probability
1.2.02.03.00	Fault movement shears waste container	*Exclude*	Low Probability
1.2.03.01.00	Seismic activity (Note: Includes faulting, hydraulic heads, recharge-discharge zones, rock stresses, drift integrity)	*Exclude* for indirect effects / *Include* for drip shield and fuel-rod cladding damage	Low Consequence
1.2.03.02.00	Seismic vibration causes container failure	*Exclude* TBV for waste package / *Include* for drip shield and fuel-rod cladding.	Low Consequence
1.2.03.02.01	Container failure induced by microseisms associated with dike emplacement	*Exclude* TBV	Low Consequence
1.2.03.03.00	Seismicity associated with igneous activity	*Exclude* for indirect effects / *Include* for drip shield and fuel-rod cladding damage	Low Consequence

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.01.00	Igneous activity (Note: Also effects on faults, topography, rock stresses, groundwater temperatures & drift integrity)	*Include*: for direct effects / *Exclude*: for indirect effects	Low Consequence of Indirect Effects
1.2.04.02.00	Igneous activity causes changes to rock properties	*Exclude*	Low Consequence
1.2.04.02.01	Dike provides a permeable flow path	*Exclude*	Low Consequence
1.2.04.02.02	Dike provides a barrier to flow	*Exclude*	Low Consequence
1.2.04.02.06	Dike related fractures alter flow	*Exclude*	Low Consequence
1.2.04.03.00	Igneous intrusion into repository	*Include*	
1.2.04.03.03	Sill intrudes repository openings	*Include*	
1.2.04.04.00	Magma interacts with waste	*Include*	
1.2.04.04.01	Magmatic volatiles attack waste	*Include*	
1.2.04.04.02	Dissolution of spent fuel in magma	*Include*	
1.2.04.04.03	Dissolution of other waste in magma	*Include*	
1.2.04.04.04	Heating of waste container by magma (without contact)	*Include*	
1.2.04.04.05	Failure of waste container by direct contact with magma	*Include*	
1.2.04.04.06	Fragmentation (Note: with subsequent damage to waste package)	*Include*	

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
1.2.04.05.00	Magmatic transport of waste	*Exclude* for transport in liquid magma and other types of transport. / *Include* for transport through eruptive events	Low Consequence
1.2.04.05.01	Direct exposure of waste in dike apron	*Exclude*	Low Consequence
1.2.04.05.02	Volatile radionuclides plate out in the surrounding rock	*Exclude*	Low Consequence
1.2.04.05.03	Entrainment of SNF in a flowing dike	*Exclude*	Low Consequence
1.2.04.06.00	Basaltic cinder cone erupts through the repository (Note: Also entraining waste)	*Include*	
1.2.04.06.01	Vent jump (formerly called "wander")	*Include*	
1.2.04.06.02	Vent erosion	*Include*	
1.2.04.07.00	Ashfall	*Include*	
1.2.10.01.00	Hydrologic response to seismic activity	*Exclude*	Low Consequence
1.2.10.02.00	Hydrologic response to igneous activity (Note: Includes groundwater flow directions; water level, chemistry, temperature; change in rock properties)	*Exclude*	Low Consequence
1.2.10.02.01	Interaction of WT (water table) with magma	*Exclude*	Low Consequence
1.2.10.02.02	Interaction of UZ pore water with magma	*Exclude*	Low Consequence
2.1.07.01.00	Rockfall (large block)	*Exclude*	Low Consequence

PRELIMINARY PREDECISIONAL INFORMATION

YMP FEP Database Number	FEP Name	Screening Decision	Screening Basis
2.1.07.01.01	Rockbursts in container holes	*Exclude*	Low Consequence
2.1.07.02.00	Mechanical degradation or collapse of drift	*Exclude*	Low Consequence
2.1.07.02.03	Rockfall stopes up fault	*Exclude*	Low Consequence
2.1.07.02.04	Rockfall (rubble)(in waste and EBS)	*Exclude*	Low Consequence
2.2.06.01.00 *	Changes in stress (due to thermal, seismic, or tectonic effects) change porosity and permeability of rock	*Exclude*	Low Consequence
2.2.06.02.00 *	Changes in stress (due to thermal, seismic, or tectonic effects) produces change in permeability of faults	*Exclude*	Low Consequence
2.2.06.03.00 *	Changes in stress (due to seismic or tectonic effects) alter perched water zones)	*Exclude*	Low Consequence

NOTES: Shaded Items are Primary FEPs; others are Secondary FEPs.
* These FEPs are addressed by multiple FEP AMRs , see the YMP FEP Database (CRWMS M&O 1999d)
SNF = spent nuclear fuel; EBS = engineered barrier system.